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INSTITUTE FOR CRISIS AND DISASTER MANAGEMENT
A CENTER FOR RESEARCH, TRAINING, AND EDUCATION

PORT AND WATERWAY RISK ASSESSMENT GUIDE

FOR THE U.S. COAST GUARD

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RISK AND "ACCEPTABLE RISK"

The U.S. Coast Guard Captain of the Port (COTP) is tasked by the Ports and Waterways Safety Act of 1972 (33 USC 1221, 1223, 1224) and the USCG Marine Safety Manual to maintain an acceptable level of safety in the ports and waterways in his or her area of responsibility. The Coast Guard is empowered by regulatory, enforcement, waterways management, and emergency response authorities to make the decisions and take the actions necessary to ensure that this acceptable level of safety is achieved and maintained. However, an understanding of the concepts of risk and the ability to evaluate and to manage risk are required in order to reach this goal. This guide provides a structured format for gathering and analyzing the necessary information and professional knowledge required to evaluate and manage risk in U.S. ports and waterways, and to support decisions affecting maritime safety in these waterways..

The risk of an accident is defined as the product of the probability of occurrence of the accident and the consequences or impact of that accident. An ACCIDENT is an event that has adverse consequences (e.g. injury, loss of life, economic loss, environmental damage). The primary objective of a port and waterway risk analysis is to determine the current or base level of risk in a complex system. Secondary objectives are the identification of sources of failure and error, and the identification of system factors that may cause the risk in the system to increase to unacceptable levels. Risk assessment answers three questions:

- What can go wrong?
- What is the likelihood that it will go wrong?
- What are the consequences if it does go wrong?

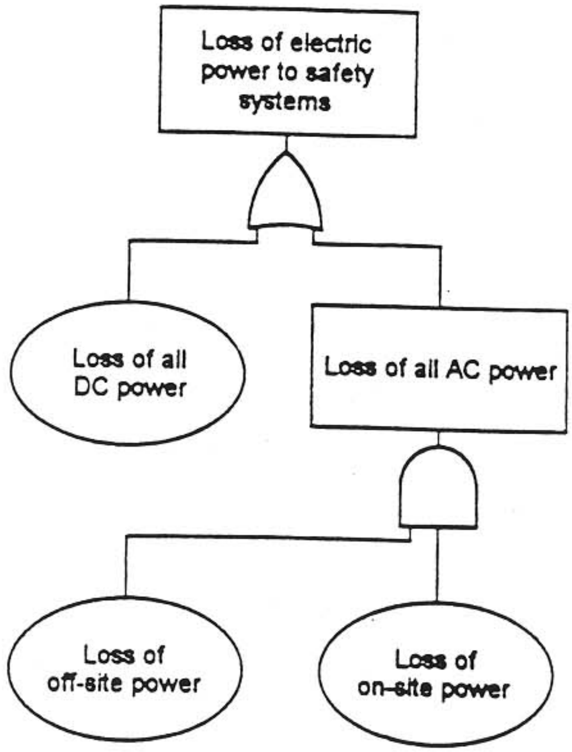
Risk management builds on risk assessment and provides the framework for achieving and maintaining an acceptable level of risk. Risk management implies that measures that can reduce the frequency and/or the impact of accidents are identified and evaluated. Risk management focuses on preventing situations and event sequences that contribute to accidents with potentially high impacts. Risk management answers the following questions:

- What can be done to prevent accidents and to minimize their consequences?
- What alternatives are available, and what trade offs must be made, and how effective are potential risk reduction safeguards?
- What are the impacts of current decisions on future options?

The determination of risk acceptability is essentially a sociological and political process that can be aided by analysis, but cannot be delegated to the analyst. Acceptability implies a subject (who is asked to accept the risk?) as well as an object (what risk should be accepted?). Acceptable risk in a system is defined by the degree to which system improvements can be identified, evaluated, accepted, and implemented. The identification and quantification of potential risk reduction measures is, therefore, an essential part of risk analysis. The determination of acceptable risk is a product of risk analysis, not an a priori assumption. This guide will assist Coast Guard field commanders by providing a coherent structure and logic for evaluating the risk in their port or waterway system, for examining the impacts of potential risk reduction measures, and for achieving a consensus on the level of risk that is acceptable.

RISK SCENARIOS

Risk scenarios are unique sets of ordered events that describe the causes and consequences of an incident of interest. An INCIDENT is an error or failure that creates an unsafe condition that may result in an accident. The sequences are composed of an initiating event (error, fault or failure) and all the subsequent equipment and/or human failures that are part of an causal chain. A fault tree may be used to represent these event sequences, if all the events in the causal chain leading to an incident are known. A typical fault tree is illustrated in figure 1. A fault tree can be evaluated using the methods of probabilistic risk assessment when the probability of occurrence of all significant events in the causal chain can be estimated.



Simplified fault tree on electric power

FIGURE 1

Similarly, if all possible significant outcomes of an incident are known, an event tree may be used to represent these event sequences. The expected value of the consequences can be evaluated using probabilistic risk assessment methodologies. In some closed systems, all possible fault trees and event trees can be identified and evaluated using historical data and expert judgment. Risk reduction measures are then evaluated by measuring their ability to interrupt or reduce the probabilities and/or consequences described in the causal chains and outcome possibilities for all accidents types.

It is difficult in a complex system such as a major port or waterway to identify even a small portion of the potential causal chains that could occur. Since the historical data required to identify and to evaluate fault tree elements is typically either not available or not reliable, evaluating fault trees for a waterway risk assessment can be cumbersome, difficult, and misleading. This is particularly true when the port operations profile is changed by new usages of the waterway (e.g. high capacity passenger vessels, new toxic cargoes). Fault trees are, however, a valid and valuable tool for the detailed analysis of the causal chain for specific incident types of interest.

RISK ASSESSMENT OF A PORT AND WATERWAY SYSTEM

A complete and systematic risk assessment is possible even when a port and waterway system is complex and critical data is missing. Three key steps are required:

- View risk as a state of the system, not as the study of isolated events.
- Use the knowledge of local experts to help define the system and to evaluate risk.
- Use available data to determine the frequency of risk states and to calibrate and augment expert knowledge.

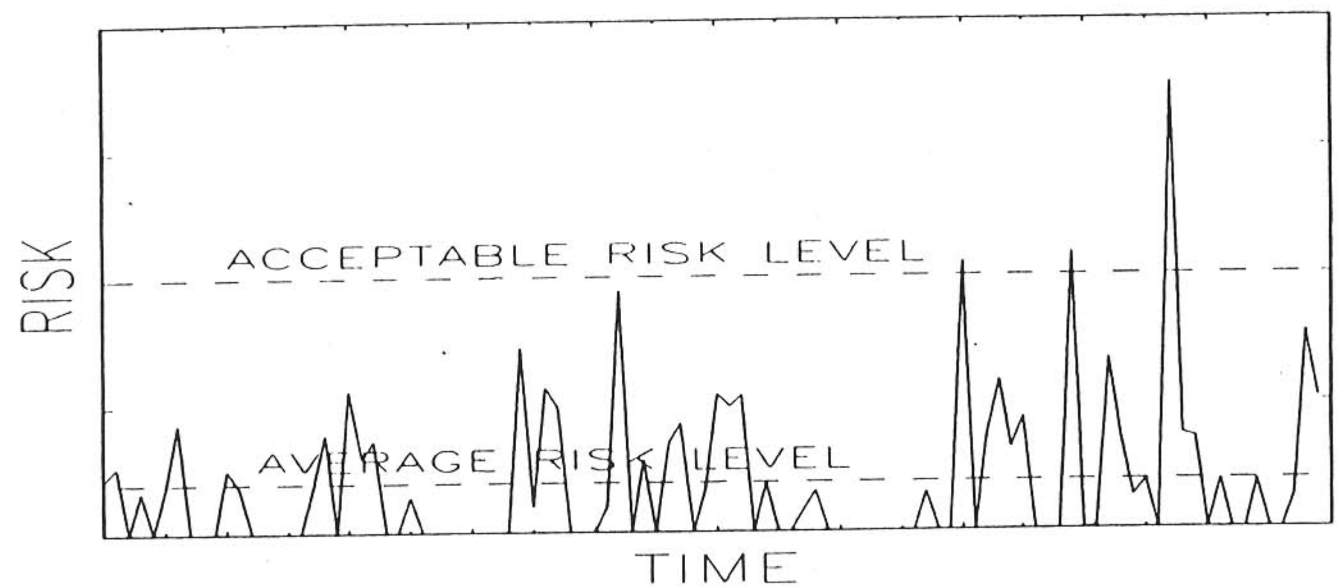
Incomplete historical data, accident case records, and local knowledge can be used to determine dominant accident types (e.g.; groundings, allisions, collisions), and to determine dominant primary causal factors for a small set of incidents (e.g.; power or steering failures, navigational error). This very rough analysis will provide the basis for a first cut risk analysis and will help determine the need for and the scope of a more detailed analysis. The dominant incident types will vary from port to port and depend upon the port configuration, vessel traffic, and weather conditions. Identifying risk reduction measures that will reduce the probability of the dominant causal factors and incident types is a also a useful product of this first cut risk assessment.

A more thorough risk assessment requires a detailed examination of possible states of the port and waterway system. A unique system state for any local waterway system can be defined by the values of a set of primary system variables such as wind, visibility, location, waterway configuration, and vessel traffic. Each risk state may be viewed as an opportunity for an accident and the probability that an accident will occur in a given state varies significantly among risk states. For example, consider a simple aviation system consisting of one airport, one pilot and one single engined plane. The pilot, trying to land the single engine plane in a violent thunderstorm, is in a "riskier" system state than if he or she were attempting the same evolution during a calm, sunny day.

The expected number of accidents in a system is simply the product of the frequency of occurrence of a system state times the probability of an accident occurring in that system state. The risk assessment process requires the identification of system states; the estimation of the frequency of occurrence of system states; and the estimation of the probability of an accident, given a particular system state. Risk is a dynamic system property, as shown in figure 2.

Risk management initiatives dampen the amplitude of risk spikes in figure 2 and decrease their frequency by identifying the states in which they occur and by implementing appropriate risk reduction measures. Identifying system states in which the most accidents occur is the first step in reducing accidents. These system states are not necessarily the system states with the highest relative probability of an accident since these states may occur infrequently, if at all.

A PROCESS CONTROL APPROACH TO RISK MANAGEMENT



- QUANTIFY RISK
- INVESTIGATE CURRENT RISK PROFILE FOR PEAKS AND AVERAGE
- FORECAST RISK PROFILE FOR SUGGESTED POLICY CHANGES
- MONITOR RISK PROFILE OVER TIME

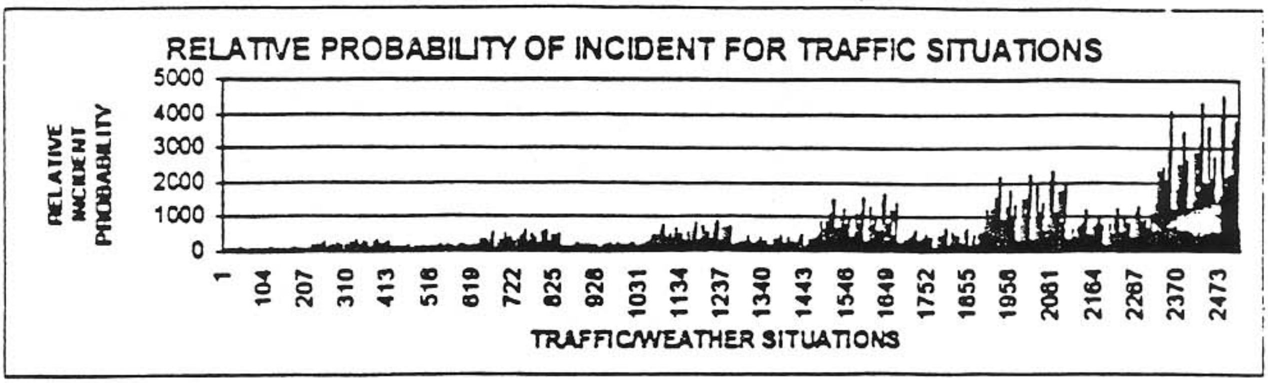
FIGURE 2

Most systems already contain formal or informal mechanisms for avoiding high risk conditions. Returning to the earlier aviation analogy, the pilot may always avoid flying when severe thunder storms are forecast. The stormy weather system state may have a high relative risk, but an accident involving the small plane will not occur in this state since the pilot does not fly in thunderstorms. The expected number of accidents in the low relative risk states (sunny days) will actually be greater.

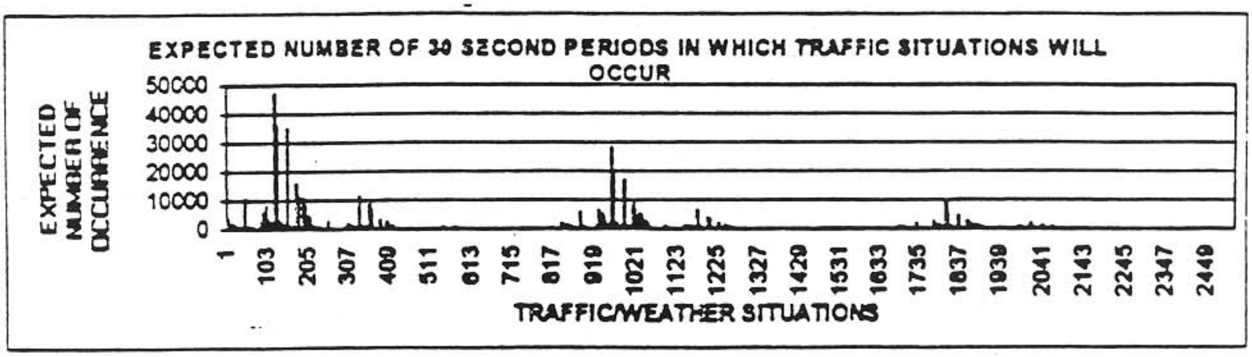
CONSIDERING THE WORST CASE IS NOT ENOUGH

Reducing the expected number of accidents means that the system states that produce the highest number of accidents must be identified. Figure 3 shows the results of the analysis of a major U.S. port. Figure 3 (a) orders the approximately states 2,500 states of this port system from lowest to highest relative probability of accident occurrence, given the system state. Note that the risk of an accident occurring if the system is in a high risk state is over 4,000 times the risk of an accident occurring if the system is in the lowest risk state. Figure 3 (b) shows the actual number of times each risk state has occurred over a over a multiple year period. Figure 3 (c) represents the product of the probability of accident occurrence given a system state times from figure 3 (a) and the frequency of each system state from 3 (b). The important result shown by figure 3 (c) is that the greatest number of accidents are expected in system states that are of moderate risk and that occur relatively frequently. High risk states occur infrequently; the professional mariners in the system and waterways managers ensure that such states are avoided. An important implication of figure 3 is that worst case scenarios, a valuable tool for response planning, should not be used as the basis for risk management. Focusing exclusively on trying to make extremely low frequency, high risk scenarios safer will, in general, not significantly reduce the expected number and consequences of accidents in a waterway system.

RELATIVE INCIDENT PROBABILITY



EXPECTED NUMBER OF OCCURRENCES (EXPOSURE)



EXPECTED NUMBER OF INCIDENT IS THE PRODUCT

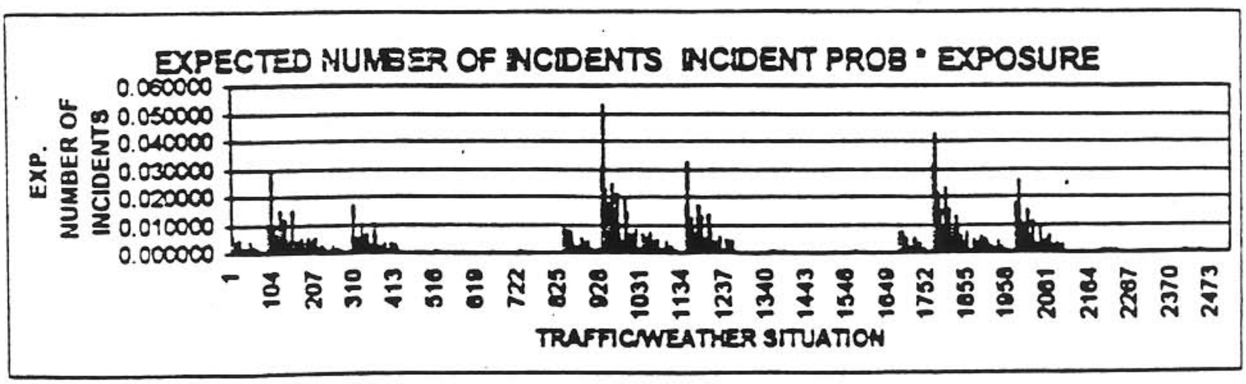


FIGURE 3

A SYSTEM BASED VIEW OF WATERWAY RISK

The probability of vessel incidents and accidents is influenced by factors internal to the vessel and by situational factors in the external environment. Although the historical data required to quantify causal relationships does not exist, experience and research have identified vessel and situational attributes that can be used as indicators of risk. The values of the vessel factors shown in table 1 are predictors of incidents due to human or organizational error (e.g.; the presence of a pilot, changes in ownership or flag) or incidents due to mechanical, electrical, or structural failure (violation/incident history, classification society, vessel age).

Situational risk may be predicted based on the values of the external factors shown in table 2 (e.g. weather, visibility, traffic, sea state, location). A bad situation can turn a minor human error or mechanical failure into a major accident; bad things can happen to good vessels in adverse situations.

Similarly, the impact of a vessel accident is also dependent upon both vessel and situational variables and on the value placed on the consequences of the accident (e.g. environmental damage, loss of life). A collision between two vessels has a very different impact if (a) both vessels are coal barges or, (b) one vessel is a high capacity passenger vessel and the other vessel is a barge carrying a toxic chemical. The outcome of a collision involving a passenger vessel may depend on the ability to render assistance after the event, which in turn will depend on the availability of response and rescue resources and the environmental conditions. Similarly, the impact of a grounding involving a tanker is dependent upon the pollution response potential and the resources at risk. Figure 4 shows how this system view of waterway risk relates to the Coast Guard's marine safety, emergency response, and waterway management functions. The Coast Guard programs effect both the frequency and the consequence of waterway accidents and provide an integrated risk management capability..

TABLE 1

SUGGESTED VESSEL DESCRIPTION PARAMETERS*

	VESSEL DESCRIPTION VARIABLES	TYPICAL VALUES
1	VESSEL TYPE	Deep Draft Calling Fleet Passenger Vessels Tank Vessels Container Vessels Bulk Cargo Vessels Special Purpose Vessels Other Shallow Draft Transit Fleet Tugs with tows Line Haul tows Fishing Vessels River/inland passenger vessels Other Shallow Draft Local Fleet Ferries Excursion boats Gambling boats Other
2.	VESSEL AGE	0-15 years 15-25 >25
3.	CLASSIFICATION SOCIETY	IACS Member IACS Associate Member Not classed by recognized classification society
4.	PILOT	Pilot on board More than one pilot on board No pilot on board
5.	FLAG	US/Canadian/Traditional Maritime Flag of Convenience Targeted Flag
6.	MANAGEMENT CHANGES	No Changes in owner, flag, or class society within 3 years Change in either owner, flag or class society within 3 years Frequent changes or Targeted owner/operator
7.	VESSEL VIOLATION/INCIDENT HISTORY	No violations or casualties within 3 years Minor violation or incidents within 3 years Repeated minor or recent major incident or violation

* For foreign flag vessels, the risk predictors developed for the USCG Port State Control program should be used.

Appendix A provides a worksheet for evaluating the relative risk of a port area calling fleet using these variables.

TABLE 2
SUGGESTED SITUATIONAL RISK PREDICTORS

	SYSTEM VARIABLE	ALLOWABLE VALUES
1.	WATERWAY CONFIGURATION	Open (fairway with good water on both sides) Restricted (shallow water or hazard near the marked channel) Converging (multiple channels that meet or cross)
2.	VISIBILITY	good adequate restricted/rapidly changing
3.	WIND	light bothersome difficult (rapidly changing or high)
4	CURRENT	none low difficult (rapidly changing or high)
5.	TRAFFIC SITUATION	single vessel simple situation (meeting, overtaking) complex situation (multiple vessels crossing/passing)
6	TRAFFIC DENSITY	no vessel within 0.5 miles one vessel within 0.5 miles multiple vessels with 0.5 miles

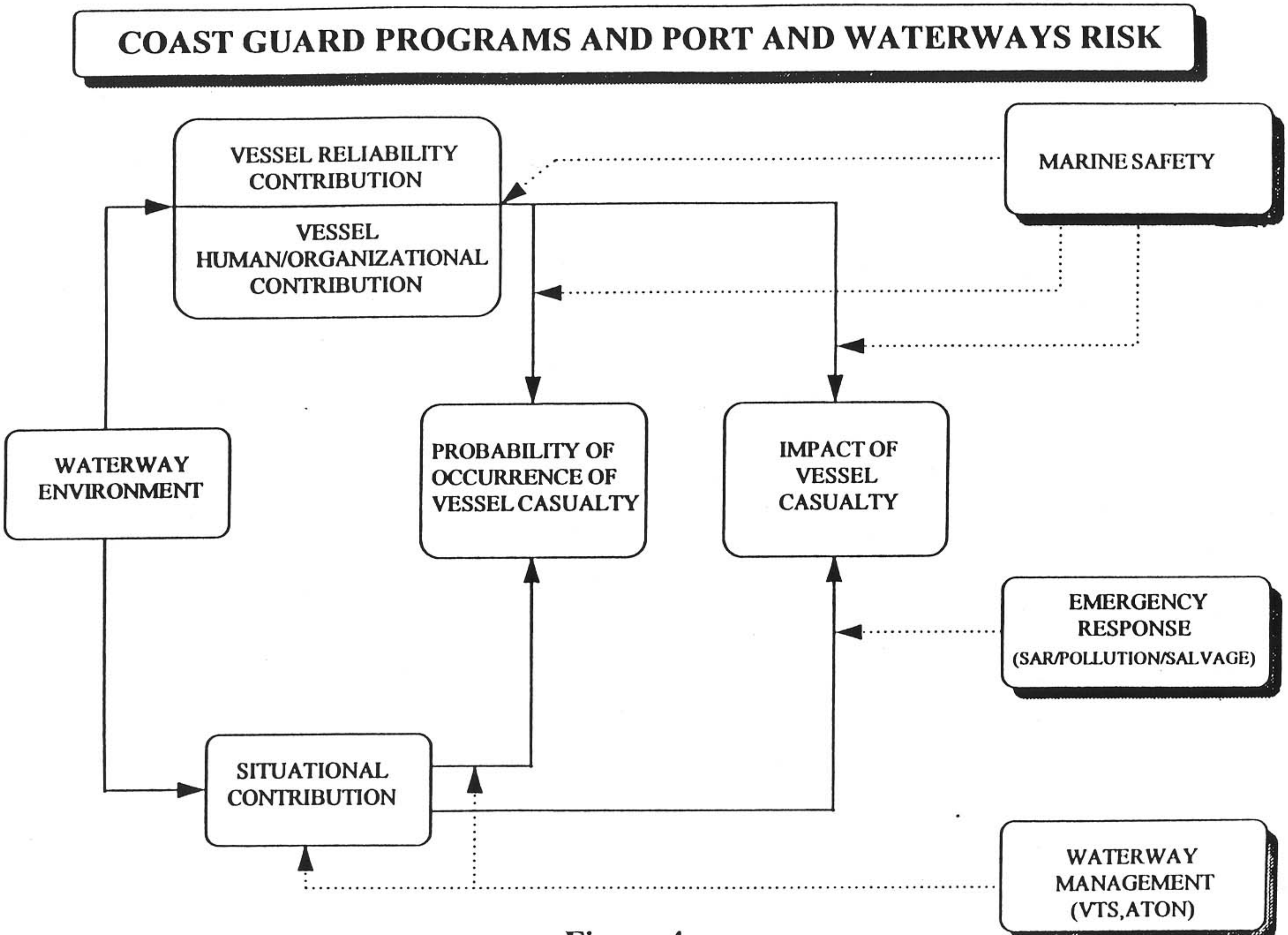

COAST GUARD PROGRAMS AND PORT AND WATERWAYS RISK
VESSEL RELIABILITY CONTRIBUTION
VESSEL HUMAN/ORGANIZATIONAL CONTRIBUTION
MARINE SAFETY
WATERWAY ENVIRONMENT
PROBABILITY OF OCCURRENCE OF VESSEL CASUALTY
IMPACT OF VESSEL CASUALTY
EMERGENCY RESPONSE (SAR/POLLUTION/SALVAGE)
SITUATIONAL CONTRIBUTION
WATERWAY MANAGEMENT (VTS,ATON)

Figure 4

A SYSTEM BASED RISK REDUCTION METHODOLOGY

Appendix A details a 12 step risk assessment methodology that incorporates a simplified scenario based analysis into a systems based approach. This methodology may be implemented as a preliminary risk analysis as described in the first section of Appendix A or it may be implemented using extensive analysis, modeling, and simulation as described in part 2 of Appendix A. The Appendix provides the USCG Captain of the Port a methodology for making a first approximation risk analysis in his or her area of responsibility that will provide an adequate basis for establishing an approximation of baseline risk, identifying significant hazards, and evaluating proposed risk reduction measures.

CRITICAL FIRST STEPS IN A RISK ASSESSMENT

The first and most critical steps required in the methodology are to define the local waterway system, identify local experts and stakeholders, and identify local and national data sources. Table 3 provides a listing of typical stakeholders that should be involved in any waterway risk project. Since the ultimate objective of a risk assessment is the acceptance of rules, procedures and investments shown to be effective in managing risk, the early involvement of stakeholders is essential. Table 4 provides a listing of local and national data sources. Local data sources often provide the most reliable and complete information for a waterways risk assessment. Unfortunately, this information is often contained in paper files that may require effort to locate and to use.

TABLE 3

PORT AND WATERWAY STAKEHOLDERS

	STAKEHOLDER /EXPERT GROUP
1.	STATE PILOTS ASSOCIATION
2.	FEDERAL PILOTS ASSOCIATION
3.	USCG PORT SAFETY PERSONNEL
4.	USCG VESSEL TRAFFIC SYSTEM WATCHSTANDERS
5	USCG AIDS TO NAVIGATION TEAMS
6.	SHIPPING AGENTS
7.	TOW BOAT OPERATORS
8.	EXCURSION BOAT OPERATORS
9.	FERRY BOAT OPERATORS
10.	MARINE EXCHANGE
11.	PORT AUTHORITY
12.	MAJOR DEEP DRAFT VESSEL OPERATORS AND AGENTS
13.	MAJOR TERMINAL OPERATORS
14.	COMMERCIAL FISHING ASSOCIATIONS
15.	RECREATIONAL BOATING ASSOCIATIONS

Appendix A includes a stakeholder identification worksheet.

TABLE 4

PORT AND WATERWAY INFORMATION SOURCES

	SOURCE	DESCRIPTION	FORMAT
1	USCG MARINE SAFETY DATA	ACCIDENT DATA VIOLATION DATA VESSEL DESC. DATA	ELECTRONIC
2.	US ARMY CORPS OF ENG.	WATERBORNE COMM. RIVER STAGE	ELECTRONIC/ PAPER
3.	N.O.A.A.	WEATHER DATA CURRENT DATA	ELECTRONIC
4.	USCG MSO	INCIDENT DATA VIOLATION DATA	ELECTRONIC/ PAPER
5.	USCG VTS	INCIDENT DATA/ "NEAR MISS" DATA TRAFFIC DATA	ELECTRONIC/ PAPER
6.	PORT AUTHORITY	TRANSIT DATA ALLISION DATA	ELECTRONIC/ PAPER
7.	MARINE EXCHANGE	VESSEL DESC DATA TRANSIT DATA CARGO DATA	PAPER ELECTRONIC
8.	PILOT ASSOCIATION	VESSEL DATA TRANSIT DATA	ELECTRONIC PAPER
9.	USCG AIDS TO NAVIGATION	WAMS REPORTS (INCIDENT/HAZARDS)	PAPER

Note that data sources 4 through 9 are local data sources.

RISK REDUCTION AND RISK MANAGEMENT

A risk assessment provides a measure of the current or baseline risk in a system; identifies potential failures, and estimates the probability of occurrence and the potential consequences of these failures. The reason for performing a risk assessment is, however, to determine how to make the system safer. Determining what can and should be done are the critical aspects of risk management. An integrated risk management program will contain initiatives that achieve one or more of the following objectives, as illustrated in figure 5:

- prevent organizational conditions that permit inadequate human skills and knowledge or inadequate equipment and materiel conditions (e.g.; quality programs).
- prevent errors or failures that can cause an incident (e.g.; preventive maintenance, inspections, training programs).
- prevent incidents by avoiding high risk system states where errors or failures have a high probability of resulting in an accident (e.g.; port closures, traffic separation, traffic restrictions).
- prevent an accident given that human errors or vessel reliability failure incidents have occurred (e.g.; vessel traffic control, escort vessels).
- lessen the effects of an accident once it occurs (e.g.; double hulls, hydrostatic loading, fire protection).
- minimize the consequences of an accident (e.g.; firefighting, pollution response, search and rescue).

The acceptable level of safety or a port system is determined when the current or baseline risk is known and when consensus is reached on which risk reduction measures should be implemented.

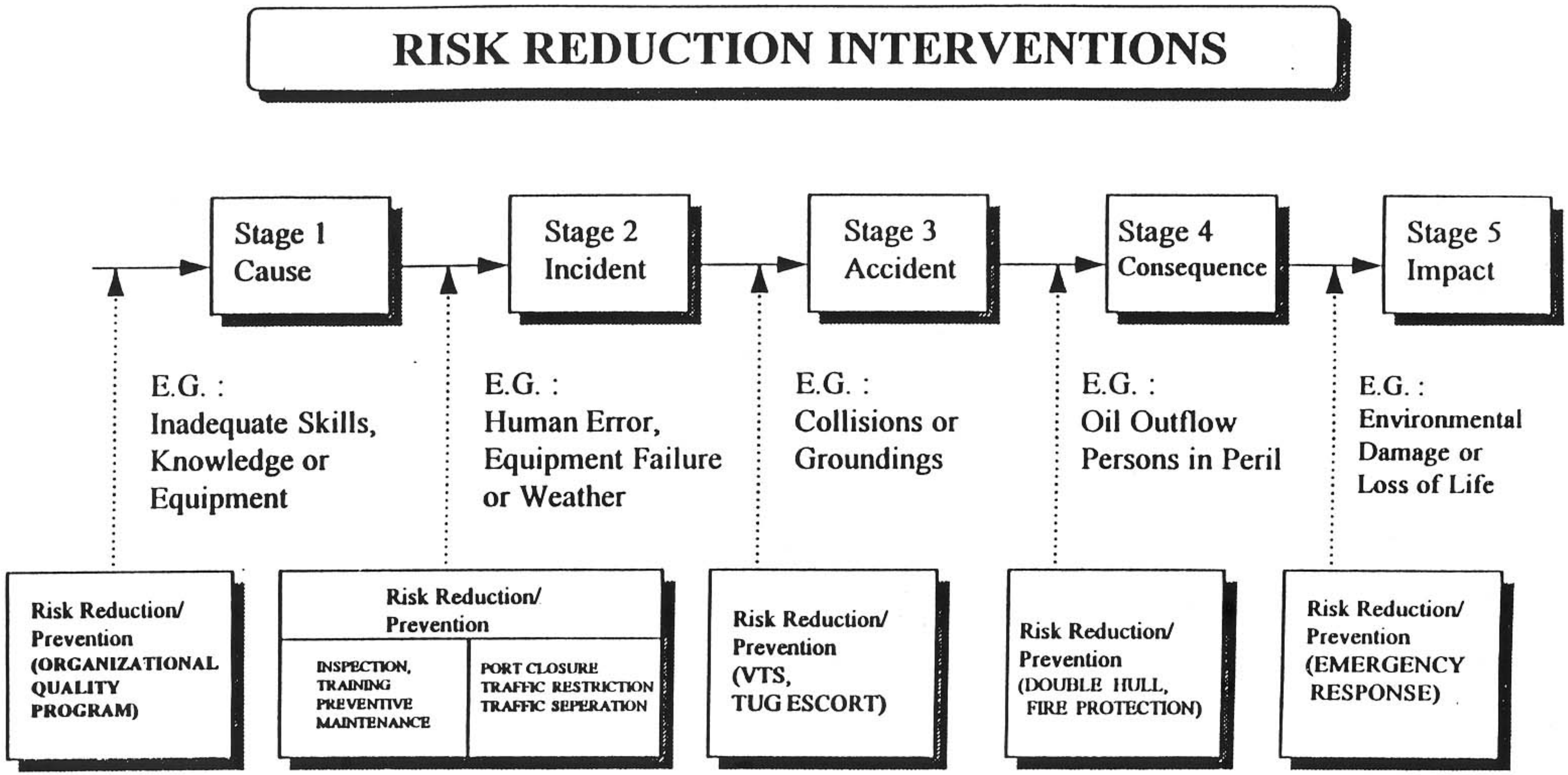


FIGURE 5

(SOURCE : Baisuck, Wallace)

Achieving consensus on a risk management plan requires that the evaluation of the impact of potential risk reduction measures answers three questions:

- How much will implementing the measure reduce the system baseline risk?
- What will implementing the measure cost and who will pay?
- What other factors should stakeholders consider when adopting risk reduction measures (e.g. technological and political obstacles, time required to implement, health and safety impacts)?

A rigorous approach to answering to these questions requires a multiple dimensional evaluation of risk reduction measures. Decision analysis methodologies such as multiple attribute utility analysis (MAU) and the analytic hierarchy process (AHP) support this type of multi dimensional decisions. In a preliminary assessment, however, risk reduction measures may be evaluated by developing subjective answers to the above questions in consultation with local experts. In a formal risk assessment, a methodology such as MAU or AHP should be used. When developing models using these techniques, however, stakeholders and local experts must be consulted to ensure that the models structure incorporates their values and knowledge.